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Water, gravity and trees: Relationship of tree-ring widths and total water storage dynamics

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Water stored in the subsurface as groundwater or soil moisture is the main fresh water source not only for drinking water and food production but also for the natural vegetation. In a changing environment water availability becomes a critical issue in many different regions. Long-term observations of the past are needed to improve the understanding of the hydrological system and the prediction of future developments.

Tree ring data have repeatedly proved to be valuable sources for reconstructing long-term climate dynamics, e.g. temperature, precipitation and different hydrological variables. In water-limited environments, tree growth is primarily influenced by total water stored in the subsurface and hence, tree-ring records usually contain information about subsurface water storage. The challenge is to retrieve the information on total water storage from tree rings, because a training dataset of water stored in the sub-surface is required for calibration against the tree-ring series. However, measuring water stored in the subsurface is notoriously difficult.

We here present high-precision temporal gravimeter measurements which allow for the depth-integrated quantification of total water storage dynamics at the field scale. In this study, we evaluate the relationship of total water storage change and tree ring growth also in the context of the complex interactions of other meteorological forcing factors. A tree-ring chronology was derived from a Norway spruce stand in the Bavarian Forest, Germany. Total water storage dynamics were measured directly by the superconducting gravimeter of the Geodetic Observatory Wettzell for a 9-years period. Time series were extended to 63-years period by a hydrological model using gravity data as the only calibration constrain. Finally, water storage changes were reconstructed based on the relationship between the hydrological model and the tree-ring chronology.

Measurement results indicate that tree-ring growth is primarily controlled by total water storage in the subsurface. But high uncertainties intervals of the correlation coefficient urges for the extension of the measurement period. This multi-disciplinary study, combining hydrology, dendrochronology and geodesy shows that temporal gravimeter measurements may give us the unique opportunity to retrieve the information of total water storage contained in tree-ring records to reconstruct total water storage dynamics. Knowing the relationship of water storage and tree-ring growth can also support the reconstruction of other climate records based on tree-ring series, help with hydrological model testing and can improve our knowledge of long-term variations of water storage in the past.